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Adoption of waste-reducing technology in manufacturing: Regional factors and policy issues☆

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ABSTRACT

The paper provides a joint theoretical–empirical investigation to assess the adoption by manufacturing firms of innovations aimed at improving waste related performance. In line with the recent emphasis on the 'external' factors stimulating innovation, which often are more important than 'traditional' drivers such as R&D, we address the role of local policy environments and regional features. We analyse firms' innovation adoption choices in a simplified technology adoption model, augmented to account for factors relevant to determining environmental innovation (EI). We frame our empirical analysis in an original integration of data from a firm level survey (Italian CIS2008 survey of manufacturing firms) and regional

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level waste related information. Our econometric analysis shows that firms adopt EI on the basis of some firm specific and relational factors, while usual drivers such as R&D have no impact. The evidence from our study supports the role of regional factors related to waste management and policy, that is, firms located in regions featuring better separated waste collection and stricter waste policy are more likely to adopt EI.

1. Introduction

Various streams of the 'economics of waste' literature explore the range of factors correlated with waste performance, including waste generation, waste recycling/waste management and waste disposal, at the macro and micro levels (D'Amato et al., 2013; Johnstone and Labonne, 2004; Mazzanti and Montini, 2009; Shinkuma and Managi, 2011). Therefore, it is surprising that the role and determinants of innovation in waste and materials/resources consumption have only recently begun to attract research attention. The diffusion of environmental innovation (EI) is crucial (Kemp and Pontoglio, 2011) to achieve sustainability and competitiveness, especially in highly industrialized countries. The literature suggests that several social, economic and policy factors contribute to explaining waste performance and, possibly, driving related innovation (Mazzanti and Zoboli, 2009; Mazzanti et al., 2008). Within this literature, there are several studies of waste generation and disposal and their drivers, that analyse regional frameworks (Allers and Hoeben, 2010; De Jaeger and Eyckmans, 2008; Dijkgraaf and Gradus, 2009, 2004; Hage and Soderholm, 2008).

Among the very few papers that focus specifically on EI in the waste realm, Horbach et al. (2012) investigate the determinants of EI in several environmentally relevant fields, and use 2009 CIS (Community Innovation Survey) data for Germany with a specific focus on the role played by (current and expected) regulation, cost savings and consumer benefits. Managi et al. (2014) analyse the technology adopted by municipalities in Japan and suggest that central government's policies may generate inappropriate incentives. We contribute to this literature by developing a joint theoretical–empirical investigation of the decisions about innovation adoption made by manufacturing firms in the waste and resources realm. We focus on the case of Italy, due to the significant degree of heterogeneity in terms of environmental and economic performance across different areas (Mazzanti et al., 2012), which has created problems related to the management of local 'hot spots'. Italy provides a vivid example of the need to boost innovation, starting at firm level, in order to reduce the consumption of material resources and related production of waste.

In line with works that highlight the external influences affecting innovation, we investigate the role of local policy environments and regional structural features. R&D investment seems to have lost its primacy among the drivers of innovation at firm level. This 'new framework' is especially applicable to radical and socially interlinked innovations such as environmental inventions and their adoption. Research is shifting the focus of analysis in non-R&D centric directions (Cainelli et al., 2012).

We develop a series of theory-based, testable implications regarding the extent to which firm behaviour is influenced by external factors, such as waste policies and infrastructures (landfill taxes, indicators of local commitment and performance related to waste, waste policy stringency, etc.). We frame our empirical analysis in an original integration of firm survey data (CIS – 2006–2008 data)[1] and regional level waste related information derived from the Italian Environmental Agency's waste reports. We use CIS2008 data because this was the first survey that asked about EI adoption. The dataset we exploit contains more than 6000 Italian manufacturing firms observed over 2006–2008. The merging of CIS data with regionally related data on waste performance is, to our knowledge, a

[1] The Community Innovation Survey (CIS) is the main and official EU survey on innovation adoption by firms. Microdata are available only at the national (not regional) level, which is one of our justifications for choosing Italian CIS data.

novel direction in the EI literature, and allows us to analyse how innovation adoption is influenced by firm-based, sector-based and geographic policy-based factors.

Our paper is mostly linked to two literature streams. First, we refer to the literature on technology adoption and environmental policy that originated with Milliman and Prince's (1989) and Downing and White's (1986) contributions.[2] The very simple theoretical model developed in Section 2 of this paper relies on the standard assumptions in that literature and derives, in particular, plausible conclusions about how waste policy (in our setting, a landfill tax and/or a waste tariff) might affect the incentives for technology adoption. Secondly, and most importantly, the present study is linked to the literature on the drivers and determinants of EI: specifically, EI adoption. Definitions of eco-innovation (Kemp, 2000, 2010) highlight the ecological attributes of specific new processes, products and methods from a technical and ecological perspective. For example, the MEI (Measuring Eco-Innovation) research project defines eco-innovation as the production, assimilation and exploitation of a product, production process, service or management or business method, that is novel to the organization (developing or adopting it), whose life-cycle results in a reduction of environmental risks, pollution and other negative impacts of resources use compared to relevant alternatives. The inclusion of new organizational methods, products, services and knowledge-oriented innovations in this definition, differentiates it from the definition of environmental technologies as all technologies whose use is less environmentally harmful than relevant alternatives (Kemp, 2010). We aim to capture the drivers of EI that are outside the firm's boundary and reside in the institutional and economic features of the territory. Theoretically, this implies the need to enrich the predictions of (policy oriented) theoretical analysis with the considerations included in a 'regional systems of innovation' approach (Beaudry and Breschi, 2003; Boschma and Lambooy, 2002; Iammarino, 2005; Iammarino and McCann, 2006), in order to investigate the key elements of regions (Cainelli, 2008; Cainelli et al., 2007) that foster waste related innovations. Several papers investigate EI drivers. These include Horbach et al. (2012) which, as already referred to, focus on the determinants of EI in several environmental realms in Germany, and Kneller and Manderson (2012) which examine the link between innovation and environmental regulations in UK. However, our contribution is, to our knowledge, one of very few studies to focus on how firm level innovation incentives are affected by local idiosyncratic features of waste related infrastructures, and by the shape of policy interventions.

The paper is organized as follows. Section 2 presents the theoretical background that informs the empirical analysis; Section 3 describes the data and models; Section 4 discusses the main econometric evidence; and Section 5 concludes.

2. Conceptual framework

This section sets out our research hypotheses with respect to the main determinants of innovation, in the form of adoption, related to waste. We focus on the impact of waste related policies and the existing waste infrastructures, and their influence on firms' adoption of less resource-intensive technologies. We discuss the role of other relevant factors, including firm specific features.

2.1. Role of policy, infrastructures and firm specific features

We model a representative economic agent (we focus on a firm, but without loss of generality) generating waste and subject to regulation. We denote the waste production level as g. Our theoretical framework is purposely stylized, so that g is intended broadly to measure the environmental impact of waste related choices taken by the agent: thus, it might quantify waste generation as well as the environmental impact of the firm's waste management practices more generally.

The regulated firm features an existing technology, denoted by the waste reduction cost function $c(g,\theta)$; parameter θ measures firm specific characteristics that the literature suggests are significant drivers of eco innovation (Horbach et al., 2012). Relevant firm specific factors include technological

[2] For a very good survey, see Requate (2005).

capability improvements led by R&D, organizational innovations such as the adoption of Environmental Management Systems (EMS, Rennings et al., 2006), and the quality of the available knowledge transfer mechanisms according to the sources of knowledge and the firm's effectiveness at using the information.

The waste reduction cost function $c(\cdot)$ satisfies, for any given value of θ, standard assumptions: $c_g(\cdot) < 0$ – costs decrease with waste production (or, more broadly, with poorer waste management by the firm) – and $c_{gg}(\cdot) > 0$.[3]

We expect better firm specific characteristics to imply, ceteris paribus, lower costs, so that we assume that $c_\theta(\cdot) < 0$. Also $c_{g\theta}(\cdot) > 0$, that is, a larger θ implies a smaller (absolute value of the) marginal cost related to g: in other words, the larger is θ, the weaker are the incentives for the regulated firm to reduce costs by increasing g.

We address the role played by waste policy and waste related infrastructures in a simplified way. More specifically, these factors are subsumed in a unit payment for waste (e.g. a waste related tax), $t = t(\beta, \delta)$, where β is a measure of the waste policy stringency (a larger β implying stricter regulation), and δ is a measure of the state of waste related infrastructures, with a larger δ implying worse waste related infrastructures. Parameter β can be intended as a measure of the authorities' commitment to lower waste production and/or the impact of firms' waste management practices, for example, in the form of higher unit waste taxes or tariffs. A larger value of δ, on the other hand, can be linked to existing separated collection or landfill rates. We assume that $t_\beta > 0$, that is, waste production (or, more generally, a larger environmental impact related to waste management) is perceived as more costly under stricter regulation. On the other hand, t_δ can be positive or negative: if it is positive, then a relatively poor state of existing waste related infrastructures implies a larger unit payment for regulated firms, for example, due to the need for the waste management authorities to cover relatively large landfill costs. If t_δ is negative, then a better state of waste related infrastructures results in a larger unit payment for waste related impacts; this can occur, for example, if better separated collection facilities imply that the relative "price" of separated collection over undifferentiated waste production decreases (i.e. the relative "price" of high impact waste practices increases). In this second case, a better state of waste related infrastructures acts in the same direction as a stricter waste policy.

Finally, we model technology adoption, assuming that the firm can choose to install a new technology featuring lower waste reduction costs for any given level of waste production and of the value of parameter θ. More specifically, by paying a fixed cost F, the regulated firm can reduce the costs $c(\cdot)$ by the factor $0 < \alpha < 1$, the smaller the factor the larger the cost savings due to the new technology. Thus, if the new technology is adopted, the cost of waste reduction (and, therefore, the cost advantage of increasing waste production) decreases.

The agent's cost minimization problem under the existing technology can be written as:

$$\min_g C_o = c(g, \theta) + t(\beta, \delta)g \quad (1)$$

where the subscript o labels the "old" (i.e. existing) technology. Given the assumption of a convex cost function,[4] the first order (necessary and sufficient) conditions with respect to g imply:

$$c_g(\cdot) + t(\cdot) = 0, \quad (2)$$

resulting in a waste level g_o; the corresponding signs of the comparative statics are as reported in the second column in Table 1.[5] As expected, a stricter waste policy and better firm specific features imply lower levels of waste production. The impact of waste related infrastructures, however, is ambiguous.

The corresponding firm's problem when the new technology is adopted is:

$$\min_g C_n = F + \alpha c(g, \theta) + t(\beta, \delta)g \quad (3)$$

[3] Coherently with the existing literature (e.g. Requate, 2005), the cost function $c(g,\theta)$ can be interpreted as measuring the costs of reducing waste to some level g below the laissez-faire (unregulated) level.

[4] We limit our attention to interior solutions.

[5] Details concerning comparative statics are provided in Appendix A, Table A1.

Table 1
Comparative statics.

Parameter	Existing technology (g_o)	New technology (g_n)
Policy strictness (β)	–	–
Infrastructures (δ)	+/–	+/–
Firm specific features (θ)	–	–
New technology cost savings (α)	0	+

where subscript n denotes the 'new technology'. First order (necessary and sufficient) conditions are:

$$\alpha c_g(\cdot) + t(\cdot) = 0, \tag{4}$$

implying a waste level g_n and the comparative statics reported in the third column of Table 1. Comparing (2) and (4), and accounting for the convexity of $c(\cdot)$ with respect to g, we can easily conclude that, for given parameters values, $g_o > g_n$. Finally, we should note that a larger cost reduction potential of the new technology (a smaller parameter α) implies a smaller amount of waste produced using the same technology, which is a reasonable conclusion.

In order to assess the incentives for the firm under scrutiny to adopt the cleaner technology, we define the net cost gain from adoption as follows:

$$\Delta = c(g_o, \theta) - \alpha c(g_n, \theta) - F + t(\beta, \delta)(g_o - g_n) \tag{5}$$

that is, the difference arising between the equilibrium costs with the existing technology and those with the new technology. Clearly, a negative value of Δ implies that adoption does not take place, while incentives for adoption are stronger the larger the value of Δ. We can now turn to the main results of our theoretical analysis.[6]

Result 1. *A stricter waste policy implies larger adoption incentives, namely the effect induced by the policy is improved technology adoption.*

Result 1 is indeed reasonable: a stricter waste policy implies a larger unit payment $t(\cdot)$, making the adoption of the new technology (and the resulting decrease in equilibrium waste production) more attractive.

Result 2. *A better state of the 'waste management related infrastructures', for example, in the form of better separated collection systems, has an ambiguous impact on adoption incentives.*

The state of waste related infrastructures can lead to larger or smaller adoption incentives: in particular, when $t(\cdot)$ increases as existing infrastructures improve (i.e. as δ decreases), then better waste related facilities – for example, proxied by larger (smaller) separated collection (landfill) rates – act exactly as a stricter waste policy, and imply stronger incentives for technology adoption.

Result 3. *Improved firm specific characteristics can imply larger incentives for technology adoption. This is the case when firm specific factors are sufficiently effective in lowering the marginal costs of waste reduction.*

The impact of firm specific features on adoption incentives can be explained as follows: first, due to $c_{g\theta} > 0$ and to $g_o > g_n$, then $|c_\theta(g_o, \theta)| < |c_\theta(g_n, \theta)|$; in other words, better firm related characteristics have a smaller impact (in absolute terms) on the $c(\cdot)$ function when the equilibrium waste production g is set at the level arising under the old (i.e. existing) technology. This effect encourages adoption. On the other hand, the fact that $\alpha < 1$ implies that the impact of firm related characteristics is, ceteris paribus, weaker when the new technology is adopted (i.e. costs of waste reduction are affected less by a given increase in θ for any level of g when the new technology is adopted). Therefore, the net effect depends (also) on how the marginal cost reduction related to increases in g reacts to an improvement in firm specific characteristics.

[6] The proofs are reported in Appendix A.

One additional remark is needed. In our paper, we do not explicitly address other potential drivers of innovation, the most important of which are market pull factors. As Horbach et al. (2012) underline in surveying previous studies, evidence does not seem to provide strong support to the relevance of demand side factors; among others, Rehfeld et al. (2007) suggest that environmental product innovations are made tougher by the expensiveness of eco-friendly products, while Kammerer (2009) identifies the crucial role of consumer benefits in driving eco-innovation. The empirical analysis in Horbach et al. (2012) shows that the demand side is important in explaining eco-innovation (also) in the areas of recycling and use of materials. We lack comprehensive information on potential market pull factors, and leave the assessment of their impact on adoption incentives to future research.

2.2. Research hypotheses

The theoretical model suggests testable implications that can be summed up in two research hypotheses related to our empirical analysis.

H1. Idiosyncratic regional waste factors related to waste management and waste policy are positively correlated to EI.

This hypothesis is oriented to capturing 'regulatory', institutional and infrastructural aspects of waste systems that may influence adoption and EI more generally (Johnstone et al., 2012), in a regional context. The assumption of a positive correlation between waste policy stringency and commitment to improved public management of waste on the one side, and adoption incentives on the other, is based on Result 1. However, as Result 2 shows, the hypothesis of a positive link between infrastructures and EI adoption cannot be taken for granted. We also expect regional idiosyncratic factors to be more significant than the usual geographical factors captured by geo-dummies, for explaining EI adoption. We use two regional waste management and waste policy related proxies to test diverse elements of the 'decentralized environment': (i) regional performance in separated collection of municipal waste; (ii) diffusion of the new waste tariff. The new waste management tariff was introduced by Italian Legislative Decree No. 22/1997 and, in theory, was expected to be an improvement on the former waste management tax by making total tariff payments increase with actual waste production.[7] However, because Legislative Decree 22/1997 provides for a transition phase that has proven gradual and very slow, a mechanism close to the earlier tax continues to be levied in many Italian municipalities. Effective implementation of the tariff system is highly dependent on local policy decisions and practices. Policy implementation is heterogeneous even across areas with similar incomes and similar socio-economic variables. The shift away from the old 'non environmentally oriented' tax is, however, expected to capture commitment towards better waste management inherent in the new tariff.

Regional separated collection performance and implementation of a waste tariff are used as proxies for regional waste management and policy strategies, measured by actual performance (partly regulatory driven) and policy commitment (e.g. taxes and tariffs). These proxies are complemented by a third measure of waste policy stringency, namely a regional landfill tax – introduced in 1996 in Italy and subject to regional competence in the definition of tax levels. Including the landfill tax provides an additional hint about the role of waste related infrastructures. More specifically, we cannot exclude the case where the landfill tax drives the results in an opposite direction with respect to the two other measures of policy commitment outlined above.

H2. The quality of information diffusion in local networks and firm specific features, such as belonging to a business group, R&D and so on, are expected to increase EI performance.

This set of drivers is linked to Result 3. Result 3 clarifies that we cannot expect all linkages to be supported by our empirical investigation. However, the intuition related to Result 3 suggests that the existence of a significant and positive impact of a subset of the considered firm specific factors according to our estimates, would (indirectly) support the view that those factors are also effective

[7] The former tax was calculated on the area of household living space; the new tariff is based on full-cost pricing principles for waste management services, and includes some market based features.

in reducing the marginal cost savings generated by a larger waste production (or a poorer waste management).

3. The data

We address our research questions using two different statistical sources. The first is the 2006–2008 wave of the Italian CIS. This survey provides information on EI for a representative sample of 6483 manufacturing firms. It also collects data on EI adoption along different dimensions. In this paper, we exploit information concerning firm level adoption of EI related to waste and material flows.

The question we focus on in the CIS survey asks: "During the three years 2006 to 2008, did your enterprise introduce a product (good or service), process, organisational or marketing innovation with any of the following environmental benefits?". More precisely, we use, as our dependent variable, the specific answer concerning 'Environmental benefits from the production of goods or services within your enterprise' in relation to <Recycled waste, water or materials>". We label the resulting variable as ECOWA.[8]

It has been established that EI adoption is generally considered a better proxy for measuring the firm's innovation capacity and intensity than environmental patents.

The second source is the dataset provided by ISPRA (the Italian Environmental Agency), which covers regional waste management and waste disposal, and provides information on regional waste policy.[9] These data allow us to link regional information on waste to firms. Although CIS data do not provide exact information on the specific location of firms, we know the region in which the firm is located, which, given the idiosyncratic features of the Italian local systems of production, is very useful (Antonioli et al., 2013; Cainelli et al., 2012). The different 'capitalistic models' of the different areas of Italy – some characterized by big firms (Lombardy, Piedmont), others by dense networks of small and medium size firms agglomerated in districts (Veneto, Emilia Romagna) – and the decentralized nature of the waste management/policy process, require an understanding of whether, and how significantly, EI adoption derives from these local/regional factors. Turning to the 'management/policy' variables associated with waste, as already outlined in Section 2.2, we focus on (i) collection of separated waste, (ii) waste tariffs, and (iii) landfill taxation, which capture different factors of the regional regulatory framework for waste management/disposal.

We merge CIS firm and waste data so that each firm is associated with well-defined heterogeneous regional – 'meso' – characteristics (Cole et al., 2009). To our knowledge, this dataset is a novelty in the environmental innovation literature. It allows us to investigate new areas of regionally-related waste performance, and to analyse the way that EI adoption is influenced by firm and geographical policy-based factors.

Table 2a provides a description of our main variables, and reports some descriptive statistics (mean and standard deviation). These variables, which refer to internal and regional 'policy' factors, are assumed to influence EI adoption. As the brief descriptions in Table 2a suggest, four categories of variables will be used in our econometric estimates. Our main dependent variable is the (already outlined) dummy variable related to the presence (or absence) of waste related EI (ECOWA). We also account for another dependent variable, related to the adoption by firms of process and product innovation in general (INNOVA), which is often correlated with EI adoption. We then have two sets of variables related to firms' features, namely, a first set of relational factors, mostly linked to information flows, and a second set of firms' characteristics, measuring productivity, R&D and other structural features. The last set of variables, already described in Section 2.2, is related to regional waste policy and performance. The econometric analysis also accounts for other more standard variables related to the size (in terms of number of employees, see Table 2b) and the geographical location of firms under scrutiny.

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8 This variable is the closest we are aware of to our empirical research focus.

9 As an exception, for the landfill tax at regional level we have used data collected and exploited in Nicolli and Mazzanti (2013); these data have been collected through the use of official regional web sites and through telephone interviews with regional offices. We thank the authors for making landfill tax data available.

Table 2a
Descriptive statistics.

	Mean	Std. Dev.	Description
Ecowa[a]	0.252	0.434	Adoption of waste related innovation
Innova[a]	0.498	0.500	Adoption of a technological general innovation (process and product)
Relational factors			
Sentg	0.432	0.495	Information on innovation received from internal sources
Ssup	0.365	0.481	Information on innovation received from suppliers
Sins	0.209	0.406	Information on innovation received from private research institutes and consultancy firms
Scon	0.214	0.410	Information on innovation received at conferences
Spro	0.125	0.331	Information on innovation received from firm's business associations
Firms internal factors			
Rtr	0.259	0.438	Presence of formal training for employees
Group	0.297	0.457	Membership to a business group
Lprod06	11.881	0.816	Labour productivity in 2006 (natural logarithm of labour productivity, given by total turnover/employees)
R&D	0.305	0.460	Presence of R&D
Regional variables			
Sep-collec	15.74	11.27	Share of regional separated collection (%) – average 2000–2005
Tarif	9.05	12.94	Share of population covered by the 'new' tariff system (%) – average 2000–2005
Land	14.53	5.51	Landfill tax level in the region (€ per ton) – average 2000–2005

N. Obs.: 6483.
[a] Dependent variables.

Table 2b
Sample structure by firm size.

	Firms		Employees[a]	
	N.	%	N.	%
1–49	4168	64.3	85,466	9.3
50–249	1533	23.6	156,253	17.1
250+	782	12.1	673,577	73.6
Total	6483	100.0	915,296	100.0

[a] Number of employees (average 2006–2008).

4. Empirical results

In our econometric specification, we estimate the following probit model (Horbach, 2008; Cainelli et al., 2012; Veugelers, 2012):

$$\Pr(Y_i = 1|X) = \Phi(X, \rho) \tag{6}$$

where Φ is the cumulative distribution function of the standard normal distribution and Y_i is a dummy variable that takes the value 1 if a firm i introduces an EI and 0 otherwise. X is the set of covariates described in Tables 2a and 2b. Our dependent variable is ECOWA – a dummy variable – which is equal to 1 if the firm adopts waste related innovation and 0 otherwise.

Table 3 reports our (baseline) econometric estimates using a bivariate probit model, which accounts for the correlation between ECOWA and the propensity to introduce technological innovations (INNOVA) at firm level. This relatedness, which occurs via correlation of the errors, can be tested by computing a simple Wald test. Analysis of this test shows that the hypothesis of no correlation between these two innovation adoption variables cannot be rejected.[10] It is well known that this hypothesis

[10] We also calculated the correlation between ECOWA and INNOVA (*0.215*); as a result a slight (though non-negligible) correlation across the two dependent variables arises in our biprobit specification.

Table 3
Factors correlated to ECOWA and INNOVA.

Estimation method	Biprobit			
Dep. var.	ECOWA [1.]		INNOVA [2.]	
	Coeff.	*t*-values	Coeff.	*t*-values
Sentg	0.117**	2.21	1.570***	22.48
Ssup	0.126***	2.67	1.235***	16.0
Sins	0.201***	4.12	0.517***	4.42
Scon	0.143***	2.99	0.686***	5.99
Spro	0.109*	1.94	0.385**	2.33
Rtr	0.183***	3.91	1.22***	10.29
Group	0.123***	2.64	−0.220***	−2.99
Lprod06	0.066**	2.53	0.84**	2.25
R&D	0.014	0.29	0.701***	7.09
D1-49	Ref.	Ref.	Ref.	Ref.
D50-249	0.096**	2.03	−0.007	−0.09
D250+	0.408***	6.03	0.008	0.06
North-West	0.014	0.13	0.329*	1.79
North-East	0.170	1.52	0.286	1.55
Centre	0.124	1.05	0.079	0.40
South	0.169	1.40	0.114	0.58
Islands	Ref.	Ref.	Ref.	Ref.
Industry dummy	Yes	Yes	Yes	Yes
N. Obs.	6483		6483	
Wald test (*p* value)	0.182			

Note: Standard errors are robust to heteroscedasticity.

* Significant at 10%.

** Significant at 5%.

*** Significant at 1%.

is crucial for understanding whether the phenomenon of eco-innovation adoption is correlated with the general propensity to innovate. In this case, adoption of ECOWA seems to be a phenomenon that can be treated in isolation from INNOVA. This allows us to estimate our (baseline) specification adopting a simple probit model. Table 4 presents the coefficients (column [1.]) and the related marginal effects (column [2.]) of the same (baseline) econometric specification as in Table 3, estimated using this model. The main conclusions based on Table 4 can be summarized as follows. The information from various ‘sources’ is positively correlated to ECOWA. This confirms the ‘relational’ needs and content of EI. In order to innovate, firms exploit their networks. Somewhat surprisingly, R&D is not statistically significant for determining waste specific EI. This is a peculiar feature of the waste related EI adoption under scrutiny, while R&D turns out to be relevant for explaining innovation in broader terms (see Table 3, column “INNOVA”). Among the firm specific variables, the dummies for whether workers receive a training programme and whether the firm belongs to a business group are positively correlated with EI and statistically significant. The latter result is not unexpected since the business group is the organizational form adopted by Italian firms that want to grow (Cainelli and Iacobucci, 2007). Also, the lagged labour productivity variable seems to have a positive and statistically significant effect on adoption of ECOWA. The evidence on firm specific features implies that support for our testable implication H2 is mixed: improvements in some of the firms’ characteristics (such as the ability to exploit information sources and labour productivity) imply a larger willingness to adopt EI, indirectly also suggesting that such characteristics can indeed be relevant for reducing the incentive for firms to increase their environmental impact to achieve short-run cost savings. On the other hand, firm specific features which, in principle, would be expected to influence EI more broadly (namely general R&D), do not seem to matter for waste and resources related adoption.

Next, we move to analyse the impact of geographic related waste management/policy factors. Given that, as Table 4 suggests, geographical dummies are not statistically significant, we need to explore other regional factors.

Table 4
Factors correlated to ECOWA.

Estimation method	Probit			
Dep. var.	ECOWA			
	[1.]		[2.]	
	Coeff.	*t*-values	*dF/dx*	*t*-values
Sentg	0.116**	2.19	0.036**	2.19
Ssup	0.125***	2.64	0.039***	2.64
Sins	0.201***	4.12	0.064***	4.12
Scon	0.143***	2.99	0.045***	2.99
Spro	0.109*	1.93	0.034*	1.93
Rtr	0.184***	3.92	0.058***	3.92
Group	0.123***	2.63	0.038***	2.63
Lprod06	0.066**	2.52	0.020**	2.52
R&D	0.014	0.28	0.004	0.28
D1-49	Ref.	Ref.	Ref.	Ref.
D50-249	0.096**	2.04	0.030**	2.04
D250+	0.409***	6.03	0.138***	6.03
North-West	0.014	0.13	0.004	0.13
North-East	0.170	1.53	0.053	1.53
Centre	0.124	1.05	0.039	1.05
South	0.170	1.40	0.054	1.40
Islands	Ref.	Ref.	Ref.	Ref.
Industry dummy	Yes	Yes	Yes	Yes
N. Obs.	6483		6483	
Pseudo R^2	0.088		0.088	
AIC	6757.7		6757.7	
BIC	7015.3		7015.3	
Correctly classified	75.5%		75.5%	

Note: Standard errors are robust to heteroscedasticity.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Introducing the share of separated waste collection (Table 5, column [1]), which is a target of EU and Italian law, does not change previous results. Its statistical significance is high, which means that firms located in regions with higher levels of separated collection (higher policy commitment), are more likely to adopt ECOWA. This can be interpreted as evidence that better infrastructures (producing better performance) boost waste related EI adoption. In light of Result 2 and, consequently, testable hypothesis H1, this implies that better separated collection is perceived as reducing the opportunity costs of clean waste practices by regulated firms; as a result, incentives for adoption are stronger. As in Tables 3 and 4, geographical factors do not seem to matter, and the evidence concerning firm specific factors is confirmed. Therefore, we can conclude that larger and more productive firms promote EI, and regional waste management provides further incentives.

Columns [2] and [3] in Table 5 explore the implications of Results 1 and 2 using other proxies. We test the role of landfill taxes (column [2]) and waste tariffs (column [3]) (Mazzanti et al., 2012). Our estimates show that tariffs are positively correlated to ECOWA adoption, while landfill taxes seem, at least in this specification, to be not significant.[11] Indeed, landfill taxes address waste disposal rather than waste generation and waste management. In other words, they act at a level which is too "far" from waste production to provide any virtuous incentive along the waste filiere (Mazzanti and Zoboli, 2006) and, therefore, to encourage improvements in waste related adoption. Waste tariffs,

[11] Appendix B reports a fourth specification which addresses the three policy variables simultaneously, and acts as an additional check on our results (Tables B1–B3). We thank an anonymous referee for suggesting this extension. Notice that in this specification, the landfill tax is significant with a negative sign. This confirms that a higher landfill tax might be interpreted as a hint of a bad state of waste related infrastructures, with a related negative impact on adoption incentives.

Table 5
Factors correlated to ECOWA.

Estimation method Dep. var.	Probit ECOWA					
	[1]		[2]		[3]	
	Coeff.	*t*-values	Coeff.	*t*-values	Coeff.	*t*-values
Sep-collec	0.109**	2.16	...	...	...	...
Land	...	...	−0.175	−1.48	...	...
Tarif	...	...	...	...	0.011***	2.93
Sentg	0.116**	2.54	0.114***	2.59	0.112***	2.56
Ssup	0.126***	3.10	0.125***	3.04	0.128***	3.18
Sins	0.201***	3.94	0.200***	3.96	0.201***	3.95
Scon	0.142***	3.34	0.142***	3.30	0.139***	3.15
Spro	0.111***	4.29	0.109***	4.03	0.109***	4.00
Rtr	0.184***	4.01	0.183***	3.97	0.186***	4.12
Group	0.125***	2.98	0.116***	2.82	0.120***	2.90
Lprod06	0.064**	2.58	0.067***	2.65	0.062**	2.41
R&D	0.014	0.37	0.019	0.53	0.020	0.59
D1-49	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
D50-249	0.097***	3.00	0.101***	2.96	0.109***	2.97
D250+	0.411***	10.05	0.418***	11.01	0.433***	10.26
North-West	−0.216	−0.98	−0.013	−0.08	−0.076	−0.41
North-East	−0.050	−0.22	0.222	1.13	−0.184	−0.86
Centre	−0.019	−0.09	0.134	0.77	−0.043	−0.23
South	0.117	0.60	0.145	0.77	0.161	0.85
Islands	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Industry dummy	Yes	Yes	Yes	Yes	Yes	Yes
N. Obs.	6483		6483		6483	
Pseudo R^2	0.088		0.083		0.090	
AIC	6717.0		6713.1		6703.7	
BIC	6845.7		6841.9		6832.5	
Correctly classified	75.6%		75.4%		75.6%	

Note: Standard errors are clustered at regional levels (20 clusters).
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

instead, are at the core of the waste management systems in Italy. The more widespread these tariffs, the more firmly the waste system is rooted in economic incentives and oriented towards full cost recovery. Other results arising from our previous analysis are confirmed, in particular with respect to firm-related factors. Again, as in previous tables, firm's R&D efforts do not appear to be a statistically significant firm specific factor.[12]

5. Conclusions

The paper presented a theoretical–empirical investigation of manufacturing firms' innovation adoption decisions aimed at improving waste performances. Our emphasis on external innovation factors as possibly being more important than 'classic' drivers such as R&D, allowed us to focus on the role of policy environments and structural regional features.

Our main results can be summarized as follows. First, firms located in regions where policy commitment to improve separated waste collection is stronger, are more likely to adopt waste related innovations. In contrast, we find that 'pure' geographical effects are not statistically significant: EI

[12] We also performed estimates by interacting our regional policy variables (e.g. separated collection interacted with the landfill variable, and so on). The results are not particularly exciting, and interactions are either weakly statistically significant or even not significant. For this reason we do not report these estimates in the text. They are available upon request.

adoption, therefore, is affected by specific regional policy attitudes in relation to environmental/waste issues rather than by broadly defined regional features. The role of policies is confirmed by the evidence concerning the introduction of a new and decentralized waste tariff, which is statistically significant and affects adoption incentives positively. These econometric results are coherent with the current North–South divide related to separated waste collection policy commitment in Italy, and are worrying in that they would seem to suggest that environmental management and policy effects might further reinforce the existing technological divide among firms located in different areas, and might increase economic and environmental differences.

Second, in contrast to much existing work on innovation, waste related innovation seems not to be sensitive to the presence of R&D, while other firm specific features, such as the availability and ability to exploit information sources and labour productivity, have a positive impact on adoption incentives. In other words, specific policy commitment and firm characteristics related to efficiency and to networking attitudes are necessary to explain EI adoption in the waste realm, while more general indicators of the propensity to innovate, such as the presence of R&D, do not seem to matter.

Further research could focus on even more localized spatial effects occurring at the provincial and municipal levels. Original survey data would be needed for such an investigation.

Appendix A.

See Table A1 for comparative statics details.

Proof of Result 1. Differentiating (5) with respect to β we get:

$$\frac{\partial \Delta}{\partial \beta} = c_g(g_o,\theta)\frac{\partial g_o}{\partial \beta} - \alpha c_g(g_n,\theta)\frac{\partial g_n}{\partial \beta} + t(\cdot)\frac{\partial (g_o - g_n)}{\partial \beta} + (g_o - g_n)t_\beta(\cdot).$$

As first order conditions (2) and (4) require $c_g(g_o,\theta) = \alpha c_g(g_n,\theta) = -t(\cdot)$, then we are left with $\partial\Delta/\partial\beta = (g_o - g_n)t_\beta(\cdot) > 0$. □

Proof of Result 2. Waste related infrastructures affect adoption incentives through parameter δ; following the same reasoning as in the proof of Result 1, we can conclude that $\partial\Delta/\partial\delta = (g_o - g_n)t_\delta(\cdot)$, that can be either positive (if $t_\delta > 0$) or negative (if $t_\delta < 0$). □

Proof of Result 3. Differentiating (5) with respect to θ we get:

$$\frac{\partial \Delta}{\partial \theta} = c_g(g_o,\theta)\frac{\partial g_o}{\partial \theta} - \alpha c_g(g_n,\theta)\frac{\partial g_n}{\partial \theta} + c_\theta(g_o,\theta) - \alpha c_\theta(g_n,\theta) + t(\cdot)\frac{\partial (g_o - g_n)}{\partial \theta}.$$

Accounting for $c_g(g_o,\theta) = \alpha c_g(g_n,\theta) = -t(\cdot)$ from (2) and (4) we are left with $\partial\Delta/\partial\theta = c_\theta(g_o,\theta) - \alpha c_\theta(g_n,\theta)$.

Under the assumption that $c_{g\theta}(\cdot) > 0$, and accounting for $g_o > g_n$ then $|c_\theta(g_o,\theta)| < |c_\theta(g_n,\theta)|$ so that $(c_\theta(g_o,\theta)/c_\theta(g_n,\theta)) < 1$. We can therefore conclude that: $\partial\Delta/\partial\theta > 0$ when $(c_\theta(g_o,\theta)/c_\theta(g_n,\theta)) < \alpha < 1$, while $\partial\Delta/\partial\theta < 0$ when $\alpha < (c_\theta(g_o,\theta)/c_\theta(g_n,\theta)) < 1$. As a consequence, $\partial\Delta/\partial\theta > 0$ requires that $c_\theta(g_o,\theta)/c_\theta(g_n,\theta)$ is sufficiently small, i.e. that $c_{g\theta}(\cdot)$ is sufficiently large to guarantee that $|c_\theta(g_n,\theta)|$ is sufficiently larger than $|c_\theta(g_o,\theta)|$. □

Table A1
Comparative statics.

	Existing technology	New technology
Policy strictness (β)	$\frac{\partial g_o}{\partial \beta} = -\frac{t_\beta(\cdot)}{c_{gg}(\cdot)} < 0$	$\frac{\partial g_n}{\partial \beta} = -\frac{t_\beta(\cdot)}{\alpha c_{gg}(\cdot)} < 0$
Waste related infrastructures (δ)	$\frac{\partial g_o}{\partial \delta} = -\frac{t_\delta(\cdot)}{c_{gg}(\cdot)} \geq 0$ if $t_\delta \leq 0$	$\frac{\partial g_n}{\partial \delta} = -\frac{t_\delta(\cdot)}{\alpha c_{gg}(\cdot)} \geq 0$ if $t_\delta \leq 0$
Firm specific features (θ)	$\frac{\partial g_o}{\partial \theta} = -\frac{c_{g\theta}(\cdot)}{c_{gg}(\cdot)} < 0$	$\frac{\partial g_n}{\partial \theta} = -\frac{c_{g\theta}(\cdot)}{c_{gg}(\cdot)} < 0$
Cost reduction under the new technology (α)	–	$\frac{\partial g_n}{\partial \alpha} = -\frac{c_g(\cdot)}{\alpha c_{gg}(\cdot)} > 0$

Appendix B.

Table B1
Additional specification.

Estimation method	Probit	
Dep. var.	ECOWA	
	Coeff.	*t*-values
Sep-collec	0.154***	3.55
Land	−0.180**	−2.49
Tarif	0.008***	3.91
Sentg	0.111**	2.55
Ssup	0.127***	3.15
Sins	0.200***	3.95
Scon	0.138***	3.09
Spro	0.112***	4.14
Rtr	0.186***	4.09
Group	0.117***	2.83
Lprod06	0.062**	2.40
R&D	0.023	0.68
D1-49	Ref.	Ref.
D50-249	0.112***	3.00
D250+	0.440***	9.85
North-West	−0.407**	−2.05
North-East	−0.351*	−1.67
Centre	−0.191	−1.03
South	0.063	0.34
Islands	Ref.	Ref.
Industry dummy	Yes	Yes
N. Obs.	6483	
Pseudo R^2	0.091	
AIC	6697.1	
BIC	6825.9	
Correctly classified	75.7%	

Note: Standard errors are clustered at regional levels (20 clusters).
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Table B2
Marginal effects (additional specification).

Estimation method	Probit	
Dep. var.	ECOWA	
	dF/*dx*	*t*-values
Separated collection	0.047***	3.53
Landfill tax	−0.055**	−2.48
Waste tariff	0.002***	3.90

Note: Standard errors are clustered at regional levels (20 clusters).
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Table B3
Correlation matrix.

	[1.]	[2.]	[3.]
[1.]	1.00		
[2.]	0.226	1.00	
[3.]	0.375	0.432	1.00

[1.] Separated collection.
[2.] Landfill tax.
[3.] Waste tariff.

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